Modified Daily Undulating Periodization Model Produces Greater Performance Than a Traditional Configuration in Powerlifters

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Abstract

Zourdos, MC, Jo, E, Khamoui, AV, Lee, S-R, Park, B-S, Ormsbee, MJ, Panton, LB, Contreras, RJ, and Kim, J-S. Modified daily undulating periodization model produces greater performance than a traditional configuration in powerlifters. *J Strength Cond Res* 30(3): 784–791, 2016—The primary aim of this study was to compare 2 daily undulating periodization (DUP) models on one-repetition maximum (1RM) strength in the squat, bench press, deadlift, total volume (TV) lifted, and temporal hormone response. Eighteen male, college-aged (21.1 ± 1.9 years) powerlifters participated in this study and were assigned to one of 2 groups: (a) traditional DUP training with a weekly training order: hypertrophy-specific, strength-specific, and power-specific training (HSP, $n = 9$) or (b) modified DUP training with a weekly training order: hypertrophy-specific, power-specific, and strength-specific training (HPS, $n = 9$). Both groups trained 3 nonconsecutive days per week for 6 weeks and performed the squat, bench press, and deadlift exercises. During hypertrophy and power sessions, subjects performed a fixed number of sets and repetitions but performed repetitions until failure at a given percentage during strength sessions to compare TV. Testosterone and cortisol were measured at pretesting and posttesting and before each strength-specific day. Hypertrophy, power, and strength produced greater TV in squat and bench press ($p \leq 0.05$) than HSP, but not for deadlift ($p > 0.05$). For squat and deadlift, there was no difference between groups for 1RM ($p > 0.05$); however, HPS exhibited greater increases in 1RM bench press than HSP ($p \leq 0.05$). Effect sizes (ES) showed meaningful differences (ES > 0.50) in favor of HPS for squat and bench press 1RM. Testosterone decreased ($p \leq 0.05$) at weeks 5 and 6 and cortisol decline at weeks 3 and 4. However, neither hormone was different at posttesting compared with pretesting ($p > 0.05$). Our findings suggest that an HPS configuration of DUP has enhanced performance benefits compared with HSP.

Key Words resistance training, program design, strength, volume, hormone response

Introduction

Periodization is a systematic approach to optimize an exercise-training program toward peak performance before a planned competition through time-sensitive manipulation of training volume and intensity (5). However, nonperiodized training excludes programmed variations to training variables such as volume and intensity (2). Currently, there are 2 primary models of periodization implemented by athletes and coaches: linear periodization (LP) and nonlinear periodization (NLP), also called undulating periodization (UP) (2). Previous research has shown LP (22,26) and UP (10,12) to increase measures of muscular performance to a greater degree when compared with a nonperiodized training program. Undulating periodization can be further modified into the more specific terms: weekly undulating periodization (WUP) or daily undulating periodization (DUP), whereas the more general term NLP could refer to either WUP or DUP without specifying.

Various studies have compared LP vs. UP for possible differences in total strength gains (1,2,16–19,21). The current body of evidence, however, shows mixed results as some studies report no differences among training models (1,2,9), whereas others suggest UP as more advantageous for strength development (16–19,21). However, a more in-depth analysis of the pertinent data reveals that LP and UP offer no significantly distinct advantages in untrained or recreationally trained individuals (1,2,7,9). Conversely, individuals with significant resistance training experience have exhibited a greater

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30(3)/784–791

Journal of Strength and Conditioning Research
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degree of muscular strength development when using a DUP design compared with LP (16–19,21).

Although DUP has shown enhanced efficacy among other periodization schemes for strength development in trained individuals, no studies have investigated programming variations within the DUP framework in experienced athletes. It is reasonable to speculate that the program design and practical implementation of DUP can be further optimized. A possible area of improvement in the DUP design is the temporal configuration of hypertrophy-centric, strength-centric, and power/speed-centric sessions within a given week. Previous research demonstrating the effectiveness of DUP over LP implemented a weekly training order of hypertrophy-centric, strength-centric, and power-centric bouts (e.g., hypertrophy training on Monday, strength training on Wednesday, and power training on Friday) (18). However, this design calls for a strength-centric bout to be performed just 48–72 hours after a hypertrophy-centric bout each week. Hypertrophy training is characterized by sessions of high volume of exercise, a condition shown to result in heightened muscle damage, and compromised neuromuscular performance for up to 48-hour postexercise (4,20). In the context of traditional DUP formatting, this may conceivably hinder performance (i.e., total volume [TV] performed) during the subsequent strength-centric bout, thereby precluding strength athletes from maximizing their training potential. Therefore, greater temporal separation between strength-centric and hypertrophy-centric bouts during each week of DUP might be more advantageous than the traditional configuration in terms of maximizing total training volume and strength development. For example, an experimental DUP model meriting further investigation comprise weekly training sessions sequenced in the order of hypertrophy-centric, power-centric, and strength-centric bouts, thereby providing a greater time frame between hypertrophy and strength sessions. The resulting training outcomes would then be compared against those derived from a traditional DUP method in which bouts are performed weekly in the order of hypertrophy-centric, strength-centric, and then power-centric sessions (HSP).

Therefore, the primary aim of this study was to compare the effects of a modified DUP format with a weekly training order of hypertrophy-centric, power-centric, and strength-centric bouts (HPS) on total training volume (i.e., sets × reps × weightlifted) and muscular strength in comparison with a traditional DUP model (i.e., HSP) in resistance-trained men for 6 weeks. In addition, a secondary aim was pursued in which the temporal secretion patterns of testosterone and cortisol were examined in response to both DUP training programs to provide insight on potential mechanisms underpinning any differential adaptive responses. It was hypothesized that HPS (i.e., modified DUP) would yield greater volume and strength gains in the 3 exercises performed during training.

Methods

Experimental Approach to the Problem

This study was designed to examine the physiological responses to 2 different 6-week training models of DUP in competitive powerlifters. Subjects were assigned to one of 2 groups in which training was performed in a fixed order each week as follows: Modified DUP with a HSP ($n = 9$) sequence or traditional DUP with a HPS ($n = 9$) sequence (Table 1). Groups were counterbalanced to ensure that there was no significant group difference in relative strength (25) or absolute strength for powerlifting total (PT) (i.e., sum of squat, bench, and deadlift) as predetermined by one-repetition max (1RM) testing.

Subjects reported to the laboratory for a total of 22 days over 8 consecutive weeks to complete the study. Weeks 1 and 8 served as pretesting and posttesting visits, respectively. Pretesting 1RM, anthropometric assessments, and blood collection were administered on day 1 of week 1, followed by taper (low volume) training 72 hours later. Weeks 2–7 consisted of a 6-week DUP training program (HSP or HPS). Subjects performed resistance training 3 days per week on nonconsecutive days during the 6-week program. Blood was collected 30 minutes before the strength-specific bout, after a 2-hour fast, each week throughout the 6 weeks of training. During week 8, subjects reported to the laboratory on only 2 occasions for taper training to allow supercompensation to set in before post-1RM testing. The first taper session was 96 hours after the completion of week 7 training, and again 72 hours later for a final 1RM testing, anthropometric assessment, and blood collection. Additionally, all subjects consumed 30 grams of whey protein (Scivation Whey; Scivation, Burlington, NC, USA) as measured by a food scale 30 minutes before and immediately after each training and testing session to ensure consistency of pretraining and posttraining feeding.

Subjects

A total of 26 subjects were screened for participation. Six of the subjects did not meet the strength criteria for inclusion. Of the 20 subjects that began the study, 2 did not complete the protocol (one from HSP and one from HPS) due to noncompliance (i.e., missing more than 2 sessions), thus a subject's data were included if 90% total compliance was achieved. Therefore, data from 18 collegiate, male powerlifters (age: 21.1 ± 1.9 years, body mass: 82.6 ± 11.4 kg, percent body fat: 9.3 ± 3.2%, height: 177.8 ± 7.9 cm) recruited primarily from the 2011, 2012, and 2013, United States of America Powerlifting (USAPL) state championship teams (i.e., The Florida State University Powerlifting Team), were used for this investigation. All subjects competed and trained raw (i.e. without the use of powerlifting supportive equipment) and were drug-free. Inclusion criteria were: (a) a 1RM back squat and deadlift at least 2 times greater than the subject's body weight, and a 1RM bench press at least 1.25 times greater than their body weight; (b) at least 5 years

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Table 1. Experimental Training Periodization Models.

	Day 1 (i.e., Monday)	Day 2 (i.e., Wednesday)	Day 3 (i.e., Friday)
Traditional DUP (HSP)	Hypertrophy	Strength	Power
Modified DUP (HPS)	Hypertrophy	Power	Strength

Traditional Daily Undulating Periodization (DUP) involves a weekly training order of hypertrophy, strength, and then power focused bouts (HSP). Modified DUP involves a weekly training order of hypertrophy, power, and then strength focused bouts. Each protocol spans 6 weeks and consists of three exercises: back squat, bench press, and deadlift (only performed during strength-centric bouts).

of resistance training experience (self-reported); (c) engaged in a structured resistance training program at least 3 times per week before the onset of the study for 1 or more years; and (e) consumption of a whey protein supplement on training days for at least the past 3 months. This study was approved by the Florida State University's Institutional Review Board. All subjects signed an informed consent before participation. Subjects also completed a health history questionnaire before partaking in any research activities.

Testing Protocol

One-Repetition Maximum (1RM) Testing and Powerlifting Total. Subjects underwent 1RM testing on 2 separate occasions: Week 1 (pretesting) and week 8 (posttesting). The 1RM testing protocol was administered on the powerlifting disciplines (back squat, bench press, and deadlift). For these sessions, subjects had their blood drawn when entering the laboratory 30 minutes before both 1RM testing days. The 3 powerlifts were performed according to USAPL regulation (25). Powerlifting total was determined by the sum of a lifter's best squat, bench press, and deadlift. The primary investigator who determined whether the lifts were performed appropriately was an experienced certified strength and conditioning specialist (CSCS) coach and USAPL coaching curriculum author. Additionally, fractional plates (to the nearest 0.25 kg) were used for measurement precision in all testing sessions.

Wilks Coefficient. Wilks coefficient is used by the USAPL to determine relative (pound for pound) strength, and the individual with the highest Wilks coefficient is determined the "best lifter" at a USAPL competition (21). This coefficient is calculated by multiplying the lifter's PT by a standardized body weight coefficient number created by Robert Wilks. This value was calculated to determine changes in relative strength.

Total Volume. For each subject, volume from each week was calculated by the product of sets × repetitions × weight-lifted from each week's strength-focused session, and then each week was summed to provide a value of TV. This was completed for each individual lift (i.e., squat TV, bench press TV, and deadlift TV), and also for the combined total volume (CTV) of all lifts.

Total Repetitions (Relative Volume). Total repetitions (TR) were determined by the amount of successful repetitions performed to USAPL standards during each week's strength-focused session and then summed to provide a value of TR. This was accomplished for each individual lift (i.e., squat TR, bench press TR, and deadlift TR), and also for the combined total repetitions (CTR) of all lifts. All lifts were monitored and supervised by the primary investigator (CSCS).

Blood Collection and Biochemical Analysis. Blood draws were administered 30 minutes before each strength-specific bout weekly and on pre-1RM and post-1RM testing days, after a 2-hour fast (8 total blood draws: 6 strength training sessions and 2 1RM testing sessions). Ten milliliters of blood was collected from the antecubital vein using a sterile, basic venipuncture technique. The blood sample was allowed to be kept in room temperature for 10 minutes before 15 minutes of centrifugation at 4° C and 3,000 rpm. Afterward, serum was separated and stored in aliquots at −20° C until analysis. Free testosterone and cortisol were analyzed in duplicate using commercial enzyme-linked immunosorbent assay kits (R&D Systems, Minneapolis, MN, USA). All assays were performed according to the manufacturer's directions. The coefficient of variation of duplicate samples was less than 5%.

Training Protocol

Both modified (HPS) and traditional (HSP) DUP protocols spanned 6 weeks, in the 2 months before the USAPL Florida State Collegiate Championships during which time exercise bouts were performed 3 times per week on nonconsecutive days (Table 1). Each bout was either hypertrophy-centric, power-centric, or strength-centric, and the order in which they were performed was determined by group assignment. The traditional DUP model (HSP) implemented hypertrophy training on day 1, strength training on day 2, and power training on day 3, whereas days 2 (strength) and 3 (power) were switched for the modified DUP format (HPS). Sets and repetitions were the same among the DUP training groups but different among the training types: hypertrophy, strength, and power.

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Each group performed 3 exercises during training: the squat, bench press, and deadlift. The squat and bench press were performed during every training session, whereas the deadlift was performed only during the strength training session of each week. During the first week of each DUP group, hypertrophy training consisted of 5 sets of 8 repetitions for the squat and bench press at 75% 1RM. During the second week of training, both hypertrophy and power days consisted of the same sets and repetitions as they did in week 1. For training weeks, 3 and 4 subjects performed 4 sets of 8 on the squat and bench press, whereas weeks 5 and 6 called for 3 sets of 8 repetitions for the squat and bench press. The load for hypertrophy was autoregulated each week dependent on each subjects' performance (14), which resulted in the training load being kept the same, increased by 5 pounds, or increased by 10 pounds. Power training was performed as follows: 5 sets of 1 repetition at 80% 1RM during weeks 1 and 2, 4 sets of 1 repetition at 85% in weeks 2 and 3, and 3 sets of 1 repetition at 90% in weeks 5 and 6. Strength training consisted of 3 sets of maximal repetitions at 85% 1RM on all 3 exercises during week 1. After week 1, the load used on strength training days progressed from week to week as follows: week 2–87.5%, week 3–90%, week 4–90%, week 5–92.5%, and week 6–95%.

Dietary Log and Body Fat Percentage

To control the diet, subjects were instructed to keep a record of their nutritional intake (all food and beverages) for each day before a resistance training session. The diet logs were given to all subjects with the instructions to replicate their food consumption 24 hours before each resistance training session. Furthermore, subjects were instructed to cease any dietary supplementation use at least 2 weeks before the study. Body fat was estimated using the average sum of 2 skinfold measurements acquired from 3 sites (abdomen, front thigh, and chest); if any site was >2 mm different among measurements, then a third measurement was taken (8). The same investigator administered the skinfold measurement for each subject.

Physical Activity Questionnaire

To obtain greater background on subjects' exercise history and qualifications for this study, each subject completed a physical activity questionnaire during his initial visit to the laboratory. Subjects provided information on how many years they had been resistance training, a description of their previous training programs, what they estimated their current 1RM to be on the back squat, bench press, and deadlift exercises, and when they competed in their last powerlifting competition. Subjects were required to refrain from all additional forms of structured exercise for the duration of the study.

Statistical Analyses

A student's *t*-test was used to test for any differences at baseline in relative or absolute strength. Pre-to-post measurements were analyzed by a 2 (group) by 2 (time) repeated-measures analysis of variance. Data were screened for normality and outliers. In the event of a significant F-ratio, a Tukey's post hoc test was performed for pairwise comparisons. Furthermore, a student's t-test was used to compare TV and relative volume (i.e., TR) among groups. Data were reported as mean and *SD* values, and significance was set at $p \leq 0.05$. Additionally, a linear regression was used to determine any relationship between individual subject TV and TR and percent change in 1RM. Finally, effect size was calculated using the Cohen's *d* model (3). All statistical analyses were performed using Statistica 12 for Windows (StatSoft; Tulsa, OK, USA).

Results

Subjects and Baseline Descriptive Measures

Subjects had an average of 6.4 ± 2.1 years of training experience, and there was no difference in years of training experience among groups. Additionally, there was no significant difference ($p > 0.05$) in any absolute or relative strength measure among groups at baseline. One subject in HSP missed 2 back squat sessions for precautionary reasons due to a minor injury (one hypertrophy and one power session), but completed all bench press sessions. No other sessions were missed in either group. Therefore, compliance for the bench press and deadlift in each group was 100%. Compliance for the back squat was 99% in HSP and 100% in HPS.

1RM Strength

Mean values for pretraining and posttraining performance variables, for both groups, can be seen in Table 2.

Individual Lift 1RM

There were main time effects ($p \leq 0.05$) for all individual lifts. For both squat and deadlift, there was no group × time interactions ($p > 0.05$). Mean percent increases in HSP were 7.93% and 6.70% for squat and deadlift, respectively. For HPS, mean percent increases were 10.48% in the squat and 7.57% in the deadlift. However, for bench press HPS increased 1RM by 8.13% (133.31 ± 17.08 to 144.14 ± 20.19 kg), which was significantly greater ($p < 0.01$) than the 2.13% increase exhibited by HSP (130.28 ± 20.07 kg to 133.81 ± 21.58 kg). Interestingly, squat and bench press 1RM effect sizes (ES) were 0.74 and 0.52 in favor of HPS.

Powerlifting Total

There was no difference among groups for PT ($p \leq 0.05$). The mean values in HSP increased from 485.19 ± 62.00 kg to 517.60 ± 60.80 kg (+6.70%) and in HPS from 506.51 ± 58.96 kg to 550.36 ± 66.67 kg (+8.66%). Additionally, effect size calculation showed a value of 0.51 in favor of HPS.

Wilks Coefficient

Hypertrophy, strength, and power, and HPS demonstrated a main time effect ($p \leq 0.05$) for Wilks coefficient. Hypertrophy, strength, and power, and HPS exhibited a 6.76% and 8.65% increase from pre to post, but there were no significant group differences for these time-dependent changes. However, there was an effect size value of 0.67 in favor of HPS.

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Table 2. Pre- and Post-training strength measures and Cohen's d effect size comparison of post-training means.

	HSP ($n = 9$)			HPS ($n = 9$)			ES
	Pre	Post	Δ (%)	Pre	Post	Δ (%)	Group favored
1RM squat (kg)	162.03 (18.67)	174.89* (18.18)	7.93	173.12 (20.76)	191.27* (25.26)	10.48	0.74 (HPS)
1RM bench press (kg)	130.28 (20.07)	133.81 (21.58)	2.71	133.31 (17.08)	144.14*† (20.19)	8.13	0.52 (HPS)
1RM deadlift (kg)	195.80 (27.54)	216.97* (26.68)	6.70	199.83 (27.53)	221.00* (27.21)	7.57	0.48 (HPS)
PT (kg)	485.19 (62.00)	517.60* (60.80)	6.70	506.51 (58.96)	550.36* (66.67)	8.66	0.51 (HPS)
Wilk's coefficient	328.08 (23.45)	350.27* (21.37)	6.76	342.74 (38.11)	372.38* (41.66)	8.65	0.67 (HPS)

HSP = Hypertrophy, Strength, Power Group, HPS = Hypertrophy, Power, Strength Group, Δ = mean relative change from pre-post training, ES = Effect Size, 1RM = One-Repetition Maximum. Values reported as means ± standard deviations.
*significantly different than Pre ($p < 0.05$), # significantly different between groups ($p < 0.05$).

Total Volume

The CTV performed (Figure 1) was significantly ($p < 0.01$) greater in HPS (31,566.02 ± 6,708.38 kg) than in HSP (44,055.56 ± 8,557.00 kg). In individual exercises, squat TV was significantly greater ($p < 0.01$) in HPS (28,261.45 ± 2,720.17 kg) compared with HSP (19,280.62 ± 1,504.94 kg), and bench press TV was significantly greater ($p < 0.01$) in HPS (16,591.27 ± 1,892.37 kg) compared with

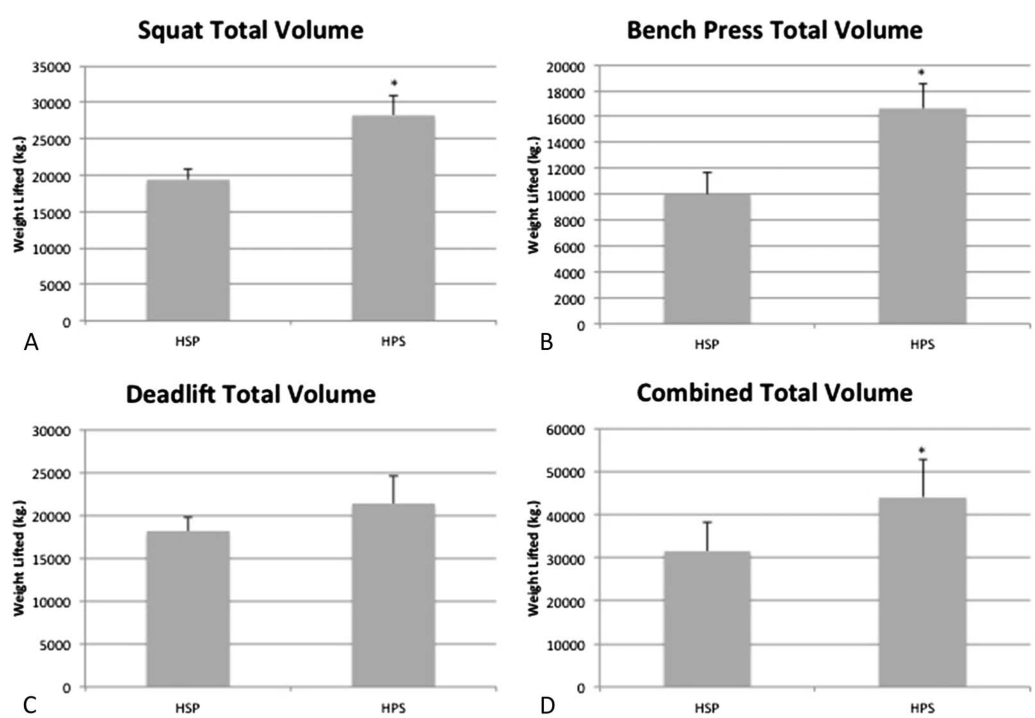

Figure 1. Total volume of strength-specific sessions in both groups. Squat total volume (Panel A.), bench press total volume (Panel B.), deadlift total volume (Panel C.), and combined total volume (Panel B.). HSP = Hypertrophy, Strength, Power, HPS = Hypertrophy, Power, Strength. Data reported as means ± standard deviations. *$p < 0.05$ = significantly greater than HSP.

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Table 3. Pre- and post-training serum testosterone and cortisol levels.

	HSP ($n = 9$)		HPS ($n = 9$)	
	Pre	Post	Pre	Post
Testosterone ($ng\cdot ml^{-1}$)	10.41 (6.71)	7.88 (7.23)	15.76 (8.07)	13.48 (9.14)
Cortisol ($ng\cdot ml^{-1}$)	43.75 (27.84)	37.21 (24.12)	39.72 (25.62)	33.00 (17.73)

HSP = Hypertrophy, Strength, Power Group, HPS = Hypertrophy, Power, Strength Group. Values reported as means ± standard deviations.

HSP (10,009.20 ± 1,704.82 kg). However, there was no significant difference ($p > 0.05$) for deadlift TV among groups.

Additionally, CTV was strongly correlated ($r = 0.68$) with percent change in PT. Further squat TV was strongly related ($r = 0.69$) to percent change in squat 1RM, as was bench press TV with percent change in the bench press 1RM ($r = 0.89$). For deadlift, there was a moderate relationship between deadlift TV and percent increase in deadlift 1RM ($r = 0.48$).

Relative Volume–Total Repetitions

Similar to CTV, CTR across all strength-specific sessions were significantly ($p < 0.01$) greater in HPS (218.22 ± 50.44) vs. HSP (297.11 ± 48.56). In the individual lifts, squat TR were greater ($p = 0.02$) in HPS (199.0 ± 25.80) vs. HSP (89.44 ± 27.49); similarly, bench press TR were greater ($p < 0.01$) in HPS (93.56 ± 22.09) vs. HSP (59.56 ± 14.23). However, there were no group differences for deadlift TR ($p > 0.05$).

Testosterone and Cortisol

There were no significant changes ($p > 0.05$) in serum testosterone or cortisol levels from pretesting to posttesting (Table 3). Furthermore, there were no changes for either hormone in HSP or HPS alone at any time point throughout the training protocol. Although no group differences were evident, there was main time effect ($p \leq 0.05$) showing a significant decrease for serum testosterone pretraining to week 5 (−31.40%) and to week 6 (−3.45%). Similarly, a main time effect ($p \leq 0.05$) for serum cortisol level noted a decrease from pretraining to week 3 (−25.67%) and again at week 4 (−32.42%), but again no group differences existed. Finally, testosterone to cortisol ratio (T/C) was not significantly different ($p > 0.05$) from pretest to posttest nor was there any significant difference ($p > 0.05$) among groups at any time point.

Discussion

This study is the first to compare 2 different configurations of DUP in resistance-trained men, and the first to analyze the efficacy of DUP specifically in powerlifters. In accordance with previous literature (17,18,21), our findings indicate that DUP is effective at increasing 1RM strength in already trained individuals in a relatively short time (i.e., 6 weeks of training). Our main findings support our hypothesis; in that TV performance and 1RM increases were greater in the modified model of DUP (HPS) as opposed to the traditional configuration of HSP. This is evidenced by significantly greater increases in 1RM bench press than HSP. Furthermore, calculation of effect size detects meaningful differences in outcomes; squat 1RM, bench press 1RM, PT, and Wilks coefficient had ES of 0.74, 0.52, 0.51, and 0.67, respectively, in favor of HPS. Implementing the usage of effect size data allows the magnitude of difference among groups to be assessed in a smaller sample size and has been previously used in periodization research (16,18). Finally, the HPS design resulted in greater CTV and CTR and also greater volume and repetitions in specific disciplines of the squat and bench press.

In accordance with previous research (16-19,21), our study demonstrated DUP to elicit significant strength enhancement. Previous studies have demonstrated the superiority of an undulating or nonlinear design over a LP model (16-19,21). The concept of UP has been postulated to be more effective than LP due to the frequency of altering training variables, thereby providing a greater variation in neuromuscular stimulation, leading to an enhanced training adaptation. Both DUP models implemented in this study were designed to train the 3 powerlifts, which are disciplines in competition and staples of a well-trained lifters program. The varying order of hypertrophy, strength, and power-type training is unique to literature and was designed to examine whether one configuration allowed athletes to train in an enhanced state of "readiness" to possibly allow for heightened performance.

The theory of designing resistance training programming to position athletes to train under conditions of readiness has been previously examined (15) using a model of flexible NLP (11). McNamara and Stearne (2010) demonstrated a model of flexible NLP to elicit greater strength than a fixed order of NLP in beginning trainees. In this study, the design of HPS allowed athletes 96 hours between a high-volume hypertrophy session and a high-intensity strength session with a power or speed session separating the 2. It was

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hypothesized that this strategy would provide athletes with a greater state of readiness during the strength session than HSP. It seems that this hypothesis was supported as HPS yielded more TV and relative volume or TR in the squat and bench press disciplines and also CTV and CTR.

Previous research has shown TV (or total work) to be the training variables most closely related to measures of muscle performance (i.e., strength and hypertrophy) (4). Indeed, the greater TV achieved by HPS during the strength session may explain the superior strength performance as evidenced by strong correlations of TV of an individual lift to percent change in that lift: 1RM squat ($r = 0.69$), bench press ($r = 0.89$), and PT ($r = 0.68$). Therefore, regarding the present findings, it would seem advantageous for powerlifters or strength athletes to configure a periodization model to maximize TV. Additionally, although hypertrophy was not measured in this investigation, data support a direct positive relationship between TV and muscle growth (4), suggesting an HPS design may also lead to greater increases in muscle hypertrophy than HSP. It is also well documented that hypertrophy, strength, and power adaptations are interrelated (24), therefore, the modified DUP design may be appropriate for a variety of athletes.

Unique to our study was the implementation of the deadlift as previous DUP studies have not directly trained or tested the deadlift (16–19,21). However, our study used a powerlifting population, which performs the deadlift in competition and had substantial previous experience with this discipline. Although, the deadlift was not performed in a DUP fashion and was only performed with a frequency of once per week (strength-specific sessions). This lower frequency, compared with 3X per week. for the squat and bench, may account for the lack of difference between groups in deadlift 1RM, deadlift TV, and deadlift TR. Interestingly, the deadlift still improved (HSP: +6.70%, HPS: +7.57%), comparable with the squat and bench press, suggesting a comparable training stimulus despite a lower weekly frequency.

Another variable unique aspect to the current investigation was the implementation of autoregulatory progressive resistance exercise or more simply autoregulation to the protocol. This method stipulates that an athlete's training load will be determined based on the previous week's performance. As described in the methods, this approach was implemented during each week's hypertrophy-type session to determine training load. Although this strategy has been used as a stand-alone method and has compared positively with LP for strength (14), it has not yet been incorporated into a DUP setup. Furthermore, we are the first to integrate autoregulation and DUP into the same periodized design. This approach seems appropriate to minimize failure of a prescribed training load on a given day and was likely beneficial to the athletes in this study.

Novelty in program design was also present in this investigation by monitoring temporal hormone response to DUP training. Although no difference among groups or resting change in testosterone and cortisol levels was observed, to our knowledge, this is the first protocol to examine anabolic and catabolic hormone response to DUP training in well-trained men. The lack of resting difference in both groups from pretraining to posttraining is not surprising as data have shown, and it may take multiple years in trained lifters to achieve a positive change in testosterone to cortisol ratio (6). Thus, the total of 8 weeks in our study was likely insufficient to achieve resting changes. Interestingly, there was a main time effect for a decrease in testosterone at weeks 5 and 6, and for cortisol at weeks 3 and 4, with no group differences. A possible explanation is the high frequency of multijoint movements may have led to a short-term overreaching stage, and previous authors have attributed hormonal decrease to accumulated muscle fatigue (13) during a training cycle. However, as subjects continued to adapt to the protocol and after a taper after week 6, supercompensation and recovery were achieved to allow for restoration of hormone concentrations.

It must be noted, however, that data have consistently shown the nature of a periodized model to be of little importance in novice individuals (1,2,7), attributable to the accelerated rate of neuromuscular gains in beginners. Therefore, one limitation in our study is that we only included well-trained men, and our results may not be applicable to the novice athlete. A novice trainee rather should concentrate on technique improvements, adherence to training, and avoiding overtraining as paramount importance instead of focusing on an optimal DUP design; as beginners will benefit substantially from early phase neuromuscular adaptations (23) regardless of periodization model. A second limitation is that we only compared 2 different DUP designs. As this is the first investigation to compare various DUP configurations, it is likely that the weekly design can still be improved on to maximize volume and in turn muscle performance.

In summary, this study demonstrated that a modified DUP design (HPS) allowed lifters to perform greater TV and TR than the traditional configuration (HSP), in one mesocycle (i.e., 6 weeks). Second, effect size calculations demonstrate greater strength improvements in the squat, bench press, and PT in favor of HPS, and these improvements may be explained by strong correlations between TV and percent change in strength.

Practical Applications

These findings demonstrate 2 important factors in accordance with the previous literature: (a). Total training volume seems to be a determinant of increased strength performance, and (b). Daily undulating periodization is an effective model to enhance 1RM strength during short-term training protocols (16-19,21) in well-trained men. Therefore, we suggest that athletes and coaches can achieve greater training volume and performance through implementation of a HPS configuration of DUP compared with HSP. However, since relatively

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few training studies exist regarding various training designs; research examining further DUP configurations is necessary. Moreover, this study integrated principles of autoregulation into the overall DUP setup with success in already well-trained lifters. Therefore, it is possible that although DUP provides an overall setup for success, further integration of periodized designs (i.e., a DUP and autoregulation programming strategy into a block and linear yearly framework) may be appropriate to optimize results. Finally, we also recommend that further research be conducted related to integrating training designs; and also that practitioners can effectively implement autoregulation within a DUP setup.

Acknowledgments

No funding was received for this project. The authors declare that they have no conflict of interest.
The authors would like to thank the subjects for their time and effort.

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